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APRIL 1992

Ontario
Environment
Environnement

15/4/92

ISBN 0-7729-9447-1

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PRINTED ON
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BIOMONITORING WITH MOSS MONITORS IN VICINITY OF THE CAMECO URANIUM REFINERY AT BLIND RIVER, ONTARIO

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I Abstract

Thirty monitoring stations were established around the Cameco Uranium Refinery near Blind River on the north shore of Lake Huron. At each station, mossbags of Sphagnum enclosed in polypropylene netting, and mossplates of Sphagnum in petri dishes covered by nylon netting, were exposed. Each month during the summer and autumn of 1987, the collectors were changed, and the exposed moss was analyzed for uranium. Both types of collector revealed similar patterns of uranium dispersal with the highest uranium levels found within the immediate vicinity of the refinery. Minor variations were found in the pattern from month to month. The vertically-oriented mossbags picked up more uranium than the horizontally-oriented mossplates. Horizontal mossplates provide a known surface area which enables rate of deposition to be calculated.

II Introduction

The flat vertically-oriented mossbag, traditionally used by the Ontario Ministry of the Environment (MOE), has proven useful for pinpointing sources of emissions and showing temporal changes (Temple et al., 1981). In order to add to the advantages of the flat mossbag and to better simulate deposition to ground vegetation, a device that combines some features of the flat mossbag and the dry deposit gauge was constructed. This mossplate is a horizontally-oriented, unidirectional device that has a solid container to minimize loss of moss and to provide a known surface area. The estimated rate of deposition to ground vegetation may be determined because the surface area is constant.

The overall purpose of this project was to test the performance of the mossplate monitoring device in the vicinity of a uranium refinery where increased levels of uranium have been found in the foliage (Spires et al., 1989). Specific objectives were:

(1) To obtain a detailed pattern of deposition of uranium around the refinery.

(2) To compare the relative collection efficiency of two types of biological monitors - the flat mossbag, and the mossplate.

III Methodology

The area studied (approximately 7 km^2) is west of the Town of Blind River (46° 19' N, 82° 98' W), and is situated on the north shore of Lake Huron.

The uranium refinery is located near the southwest corner of the study area (Figure 1). The refinery produces uranium trioxide from an ore concentrate that contains 70% uranium (Eldorado Nuclear Limited, 1978). Uranium can be released from three refinery stacks: the dust collection exhaust, the absorber stack, and the incinerator stack (Eldorado Resources Limited, 1987 a,b).

The name of the refinery changed to Cameco on June 1, 1990, due to a company amalgamation.

A network of 29 sites surrounding the refinery (Figure 1) and a control (approximately 12 km east of the refinery) were established in May, 1987.

The site location was limited to the west by the Mississagi River. The sites were in cleared corridors and relatively open areas to minimize interference with deposition and to eliminate contamination due to drip from nearby vegetation. Grassy sites were preferred to reduce the secondary deposition of contaminants due to dust and rain spatter.

Two species of Sphagnum moss, Sphagnum magellanicum and Sphagnum flexuosum, were gathered in approximately the same proportions from an uncontaminated site near Pointe Au Baril on Georgian Bay. The site was at least 100 m from the nearest road, and the moss was collected in a location removed from any influence of tree cover. Needles and other debris were removed from the moss, and the healthy shoot tips of damp Sphagnum moss were packed into the lower portion of a plastic petri dish. Nylon screening with a mesh size of 1.75 x 1.75 mm was placed over the moss to hold the moss inside the petri plate while still permitting the passage of air and water into the moss.

The mesh was secured on the outside by rubber bands and tape, and the plate mounted on a wooden support. Thirty mossplates (Figure 2) and several unexposed blanks were prepared for each sampling phase.

The mossbags were constructed using commercially-supplied Sphagum moss which was hand-cleaned to remove extraneous matter, washed with distilled water, and air-dried (Ontario Ministry of the Environment, 1983). Approximately 3 g of the dry moss was sewn into a flat pouch of polypropylene screening with dimensions of 15.5 cm x 6.5 cm, which provided approximately 100 cm^2 of moss surface area per single side (Figure 3). Mesh size of the screening was 1.0 mm x 1.0 mm.

In the field, the mossbags were oriented vertically, facing the source on plastic holders that were inserted into support tubes on stakes. The mossplates were oriented horizontally on brackets attached to the same stakes, approximately 1.5 m above the ground.

Monitoring was continuous over the period of May 22 to November 21, 1987, and involved six monitoring periods. The monitoring periods were as follows:

Exposure	Date Exposed	Date Collected	Exposure Period (Days)
1	May 22	June 22	31
2	June 22	July 13	21
3	July 13	August 4	22*
4	August 4	August 31	27
5	August 31	October 3	33
6	October 3	November 2	31

* refinery shutdown

The exposure periods varied from twenty-one to thirty-three days and were determined by the length of the refinery shutdown work scheduling and the findings of other studies. Little and Martin (1974) found that three to four weeks was an ideal exposure time; after that, the binding sites could become saturated, or deterioration of the moss would occur. Ratcliffe (1975) found that one month's exposure was necessary for mossbags to reflect spatial variation where lead deposition is slow. At the end of each phase, exposed monitors were changed for unexposed ones.

The exposed monitors were taken to the lab where the moss was oven-dried at 80 degrees C. The moss was then ground in a Wiley mill to homogenize the sample. Blank unexposed samples were treated in the same manner. All samples were sent to the MOE Lab in Toronto for uranium analysis. Background levels in the moss, as determined from the blank samples, were subtracted from the metal content values reported by the lab.

Contour maps were prepared for each phase using the computer program, TOPO, to show spatial and temporal dispersal patterns of uranium. From topographical maps, UTM coordinates were determined for each site, and corresponding values of uranium in μg/g of moss for each sampling phase were entered into the computer. Similar values were connected with isolines by the computer to show a trend from high to low metal concentration in the area. The computerized mathematical interpretation of the values resulted in gradient maps of uranium for each phase.

Ratios of uranium content in the mossbag to that in the mossplate were analyzed statistically with the VAX computer, using the SPSS package to compare the relative collection efficiency of the two types of monitors.

IV Results and Discussion

a) Distribution Patterns around the Refinery

Concentrations of uranium for each exposure period found in mossplates and mossbags as well as distances and directions from the source for each site, are shown in Tables 1 and 2 respectively. Uranium concentrations in both types of collector were highest nearest the refinery, and decreased with increasing distance from the refinery (Figures 4-14). The unusually high uranium concentrations observed (260 μg/g in mossbags, and 110 μg/g in mossplates) at Site 6 during the fifth exposure period could not be explained. The third exposure period, which coincided with the refinery shutdown, as expected, had much lower uranium levels at most sites in comparison to the other exposure periods. However, the shutdown uranium levels found in both types of monitors showed some degree of soil or dust entrainment at almost all of the monitoring locations when compared to levels found at the control location (Site 30).

From the uranium concentration contours produced, it can be determined that, during the growing season, uranium emitted from the refinery is mainly deposited to the east and northeast within 800 metres of the emission source and that data from permanent vegetation plots established earlier are representative of the area subjected to the maximum uranium loadings, and therefore can be used as a 'worst case' scenario (Spires et al 1989). A comparison of results for the shutdown and operational periods indicates that there was an increase in uranium concentrations at all sites except the control during the operational periods.

b) Comparison of Uranium Content in Mossbags and Mossplates

Although the dispersal patterns for uranium in mossbags and mossplates were similar, the uranium values were not. The ratio of uranium content in the mossbag, to that in the mossplate, varied between sites; however, a consistent change in ratio with distance was not seen. The monthly means of the ratios are shown in Table 5. These ratios varied from 2.05 to 1.02. A paired t-test that was performed on each value revealed that at a 95% confidence level, the ratios for exposures 1, 5 and 6 were significantly different from a 1:1 ratio (Table 3). Thus, the type of monitor had a significant effect on the amount of uranium collected. The vertically-oriented mossbag collected more uranium than the horizontally-oriented mossplate. This finding is not surprising when the form of the mossbag is considered. Both sides of the mossbag are exposed and can collect particles by wet deposition, impaction, and diffusion. Turbulent entrainment may occur to the lee side of the mossbag. Goodman et al., (1975) found that vertical mossbags collected more contaminants at windier sites. The greater exposure afforded by the orientation of the mossbag and the barrier presented by its rectangular shape, would be expected to increase adsorption of contaminants by the moss. Roberts (1972) attributed the greater collection of mossbags over moss on transplanted logs to the greater deposition and retention of particles by a vertical surface than a horizontal one, and to the contribution from increasing wind speeds above the ground.

Although the greater exposure furnished by the vertical orientation of the mossbag may account for increased deposition, greater loss of moss tends to occur too, particularly at windy sites. Serious undersampling by the mossbag can occur if the mossbag is not oriented at right angles to the source (Goodman et al, 1975).

Despite these anticipated problems, a comparison of concentrations of uranium collected by each type of collector for the same time periods showed that the vertical mossbags were more efficient at mapping out the maximum extent of the pollution effect. This pollution effect extended to all sites chosen for this study with the exception of the control site, 11.3 km to the east, although the main impact was within 800 m of the source.

Difficulties ensue if the mossbag is horizontally-oriented and used to determine rate of deposition to ground vegetation. Variability in pouch size and ill-defined surface characteristics (Martin and Coughtrey, 1982) make it difficult to calculate the surface area, and therefore, rate of deposition in terms of ground area. The lower surface of the mossbag is vulnerable to re-entrainment from the ground. Loss of moss from the lower surface is likely, and a small loss of moss containing metals near the collection date could cause considerable error (Cameron and Nickless, 1977). These problems can be largely overcome by using the mossplate monitor with a solid container as used in this study, since this minimizes re-entrainment and moss loss, and provides a known surface area for calculating loadings.

The results from this study have shown that the type of collector used should be determined by the purpose of the study. The vertically oriented collectors are more suited to measuring the extent of pollutant impact. The horizontal mossbag with associated plate are more suitable where relative pollutant deposition rates are required.

V Summary

An overall trend of decreasing uranium concentrations with increasing distance from the refinery was shown in both mossplates and mossbags. The greatest impact was observed to the east and northeast of the refinery to a distance of approximately 800 metres although uranium emissions from the industry impacted on all collectors except the control. The vertically-oriented mossbags consistently collected more uranium than the horizontally-oriented mossplate. The mossplate, being a unidirectional monitor, does however minimize possible re-entrainment, more accurately reflect true deposition, and enables surface rate calculations of this deposition to be made.

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VII Acknowledgements

The authors wish to express their thanks to everyone involved in the preparation of this manuscript. Thanks are extended to B. Angster-Beckett and S. Paquette who helped with the construction, exchange and processing of the moss monitors. The assistance of the staff of the Toronto Ministry of the Environment Laboratory for analysis of samples was appreciated. We are indebted to A. J. Brightman and P. Stong for typing the report.

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VIII Appendix

TABLE 1

Uranium Content* (ug/g) in Horizontal Mossplates Exposed Around Eldorado Nuclear Ltd., May through November 1987

		U(ug/g)					
Site No.	Distance and Direction from ENL	May 22 to June 22	June 22 to July 13	July 13 to ** Aug. 04	Aug. 04 to Aug. 31	Aug. 31 to Oct. 03	Oct. 03 to Nov. 02
1	213 m NNW	15.00	3.80	0.32	-	2.10	-
2	213 m NE	-	6.40	0.16	-	11.00	9.70
3	640 m NNE	0.34	0.24	0.07	-	0.51	-
4	488 m NNE	0.71	0.46	0.05	-	0.78	1.40
5	396 m NE	0.69	1.70	0.11	-	7.20	12.00
6	244 m ENE	2.70	2.70	1.30	-	110.00	7.00
7	244 m E	2.50	6.30	0.15	-	5.50	6.70
8	305 m ESE	0.92	11.00	0.06	-	1.50	1.90
9	305 m E	1.20	2.00	0.15	-	2.50	1.50
10	366 m E	0.38	1.10	0.09	-	1.00	1.10
11	366 m SE	0.52	1.90	0.06	-	0.65	0.88
12	213 m E	3.13	14.00	0.72	-	-	5.80
13	488 m SSE	0.28	0.39	0.76	-	1.50	1.20
14	305 m SSE	1.00	0.86	0.28	-	3.30	2.70
15	396 m S	-	0.10	0.12	-	1.00	1.60
16	335 m S	0.57	0.33	0.26	-	2.60	1.90
17	274 m S	1.40	1.80	0.46	-	7.60	10.00
18	335 m SW	3.30	0.40	0.29	-	3.90	1.30
19	244 m W	14.00	5.60	0.39	-	3.20	8.60
20	305 m WNW	18.00	5.10	0.27	-	5.10	1.90
21	457 m WNW	12.00	5.20	0.38	-	-	1.10
22	579 m NW	1.50	0.41	0.06	-	0.19	0.53
23	732 m NW	0.83	0.41	0.16	-	-	0.30
24	884 m NNW	0.23	0.10	0.03	-	0.19	0.08
25	1,128 m NNE	0.12	0.13	0.07	-	1.00	0.22
26	1,219 m NE	0.15	0.12	0.03	-	0.98	0.12
27	640 m SE	0.30	0.39	0.24	-	1.10	1.10
28	853 m ESE	0.15	0.22	0.03	-	0.30	0.11
29	2,315 m ESE	0.11	0.28	0.03	-	0.60	0.12
30	11,260 m E(control)	-	0.05	0.03	-	-	0.02

* No background value has been subtracted from these values. The blanks were <0.05 ug/g.

** Refinery shutdown.

Insufficient sample was available for analysis for the period August 4 to August 31, 1987.

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TABLE 2

Uranium Content* (ug/g) in Vertical Mossbags Exposed Around Eldorado Nuclear Ltd., May through November 1987

		U(ug/g)					
Site No.	Distance and Direction from ENL	22 May to 22 June	22 June to 13 July	13 July to ** 04 Aug.	04 Aug. to 31 Aug.	31 Aug. to 03 Oct.	03 Oct. to 02 Nov.
1	213 m NNW	33.10	3.80	0.71	7.20	8.40	5.20
2	213 m NE	2.18	3.80	0.25	7.10	30.00	16.00
3	640 m NNE	0.28	0.62	0.10	0.66	4.60	1.70
4	488 m NNE	0.73	1.00	0.13	-	3.30	4.70
5	396 m NE	1.30	2.40	0.03	3.50	21.00	14.00
6	244 m ENE	2.54	4.70	0.51	5.20	260.00	7.60
7	244 m E	4.86	14.00	0.62	9.00	13.00	17.00
8	305 m ESE	0.39	3.00	0.14	1.40	1.20	1.20
9	305 m E	2.31	6.30	0.32	7.20	6.70	2.90
10	366 m E	-	0.36	0.09	0.67	0.29	0.58
11	366 m SE	0.38	0.62	0.07	0.74	0.28	0.46
12	213 m E	-	21.00	2.00	9.80	6.90	19.00
13	488 m SSE	0.49	0.10	0.20	0.14	0.85	1.90
14	305 m SSE	1.30	0.72	0.43	5.60	2.50	11.00
15	396 m S	0.58	0.06	0.07	0.22	3.30	1.40
16	335 m S	0.43	0.09	0.29	0.33	5.30	2.70
17	274 m S	3.28	0.31	0.31	1.70	12.00	10.00
18	335 m SW	-	0.32	0.45	2.00	5.30	4.10
19	244 m W	6.40	0.91	0.57	5.30	7.00	8.30
20	305 m WNW	93.00	5.30	0.44	27.00	5.80	5.00
21	457 m WNW	43.00	4.30	0.30	-	4.80	1.50
22	579 m NW	1.70	0.53	0.08	0.34	0.37	0.61
23	732 m NW	1.60	0.26	0.07	0.29	0.54	0.23
24	884 m NNW	0.31	0.14	0.03	0.39	0.65	0.32
25	1,128 m NNE	0.16	0.11	0.05	0.13	0.66	0.48
26	1,219 m NE	0.17	0.12	0.06	0.18	1.50	0.21
27	640 m SE	-	0.09	0.06	0.28	0.22	0.35
28	853 m ESE	0.34	0.12	0.03	0.36	0.10	0.15
29	2,315 m ESE	0.36	0.24	0.09	0.43	0.22	0.32
30	11,260 m E(control)	0.08	0.08	0.03	0.06	0.03	0.08

* No background value has been subtracted from these values. The blanks were <0.05 ug/g.

** Refinery shutdown.

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TABLE 3

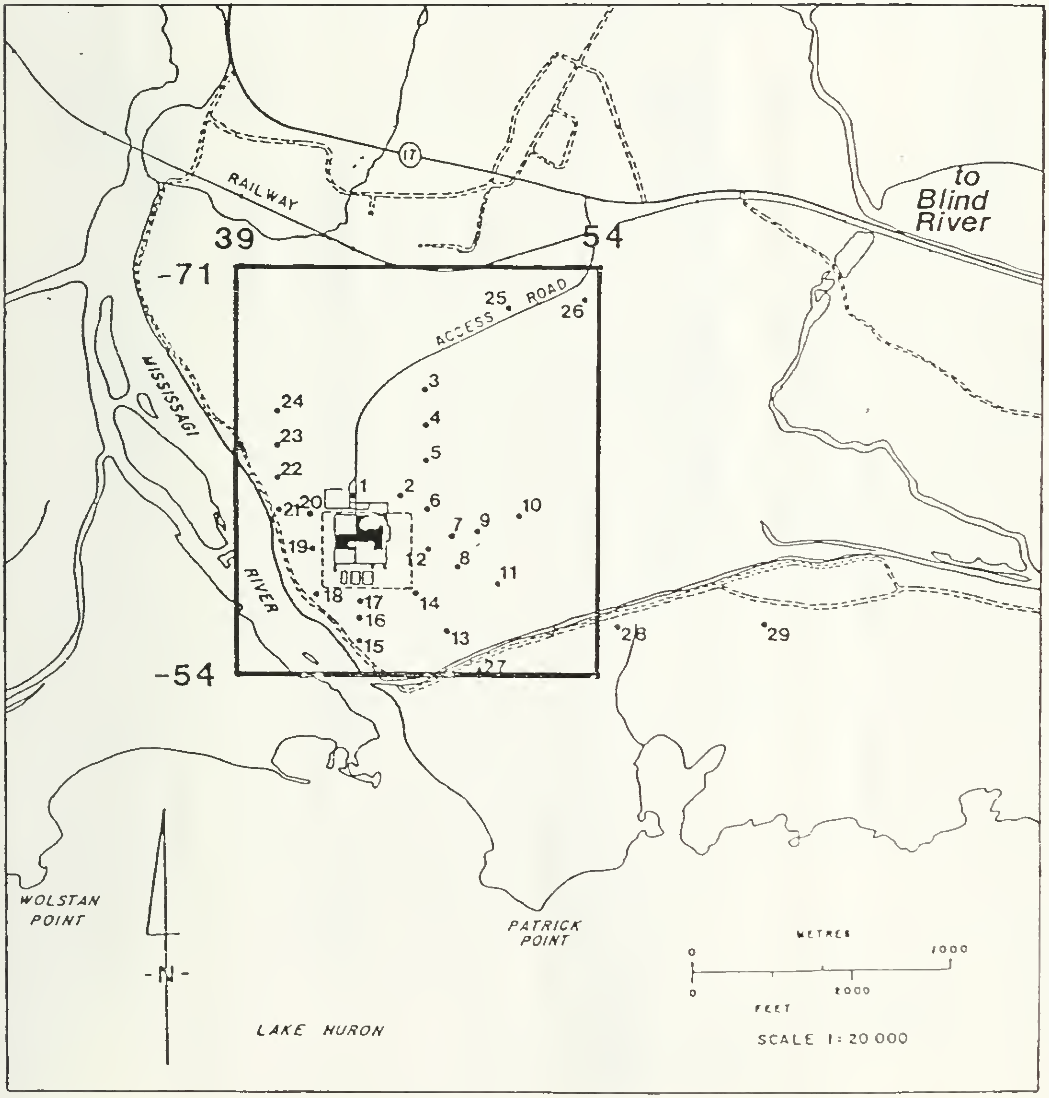
Mean Ratio of Uranium in Vertically-Oriented Mossbags to Horizontally-Oriented Mossplates for each Phase (Expressed as Means +/- Standard Error)

Phase	Dates of Phase	Mean Ratio
1	May 22 - June 22	1.70 ± 0.23*
2	June 22 - July 13	1.02 ± 0.14
3	July 13 - August 4	1.35 ± 0.16
4	August 4 - August 31	
5	August 31 - October 3	2.05 ± 1.86*
6	October 3 - November 2	1.81 ± 1.07*

* Indicates a significant difference from a 1:1 ratio ($p < 0.05$) as determined by a paired t-test.

Figure 1.

Location of Moss Monitors Around Eldorado Resources, Ltd., Blind River



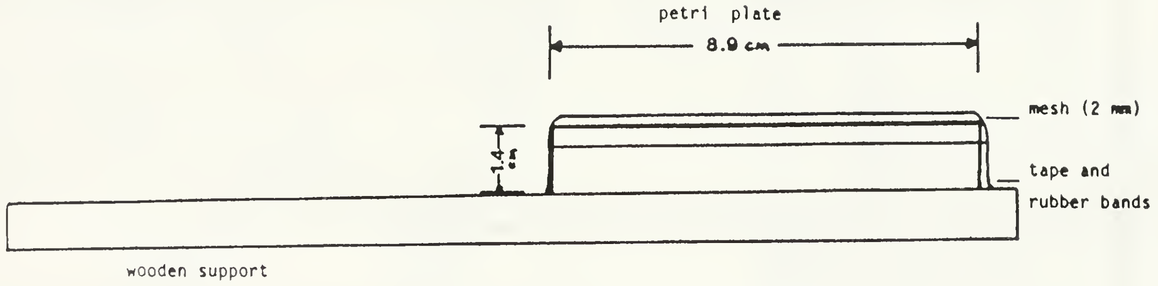


Figure 2. Diagrammatic Representation of a Moss Plate

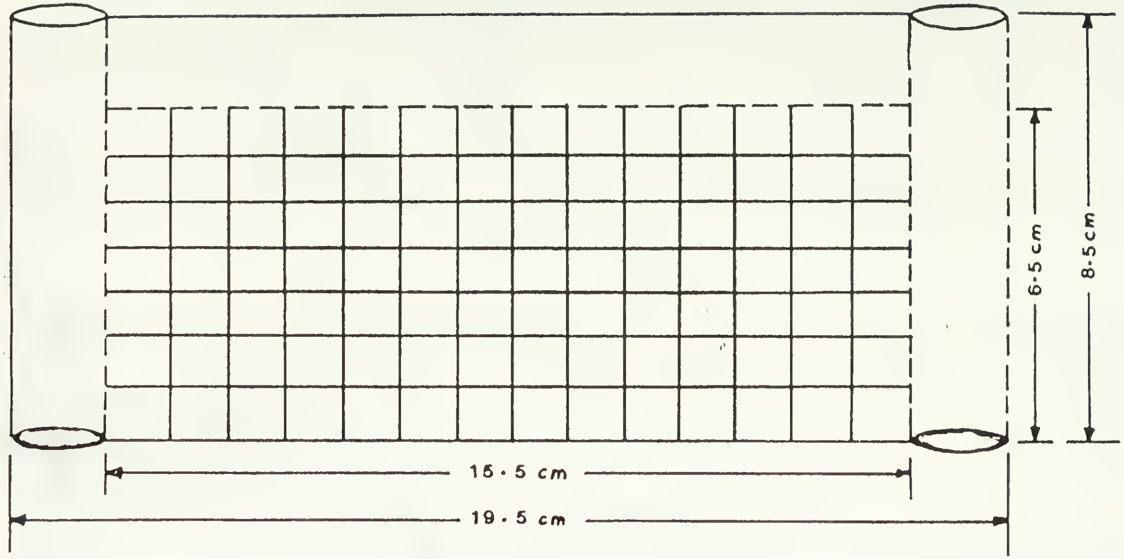


Figure 3. Diagrammatic Representation of a Moss Bag

Figure 4

Uranium Concentration (ug/g) In Horizontal Moss Plates Exposed Around Eldorado Nuclear Ltd. (★), 22 May To 22 June

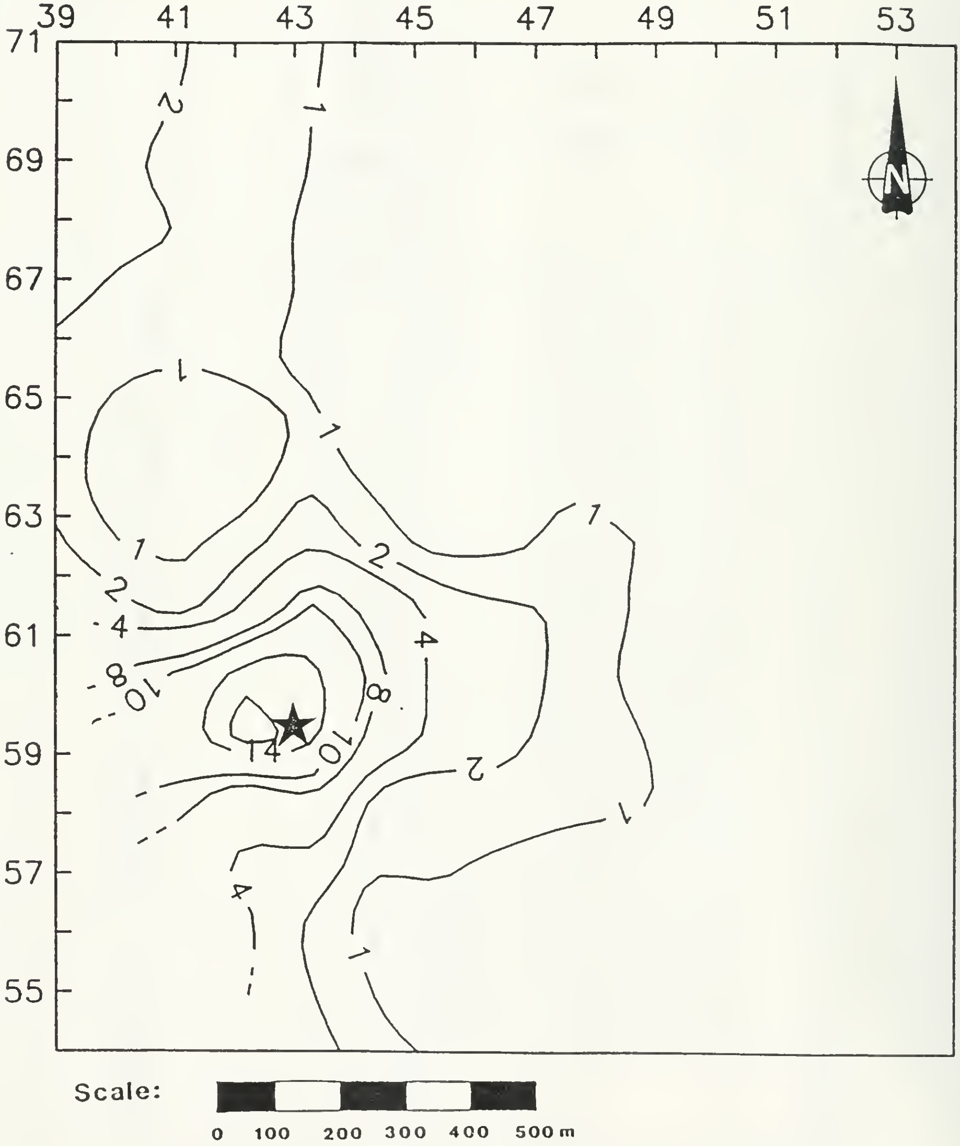


Figure 5

Uranium Concentration (ug/g) in Horizontal Moss Plates Exposed Around Eldorado Nuclear Ltd. (★), 22 June To 13 July

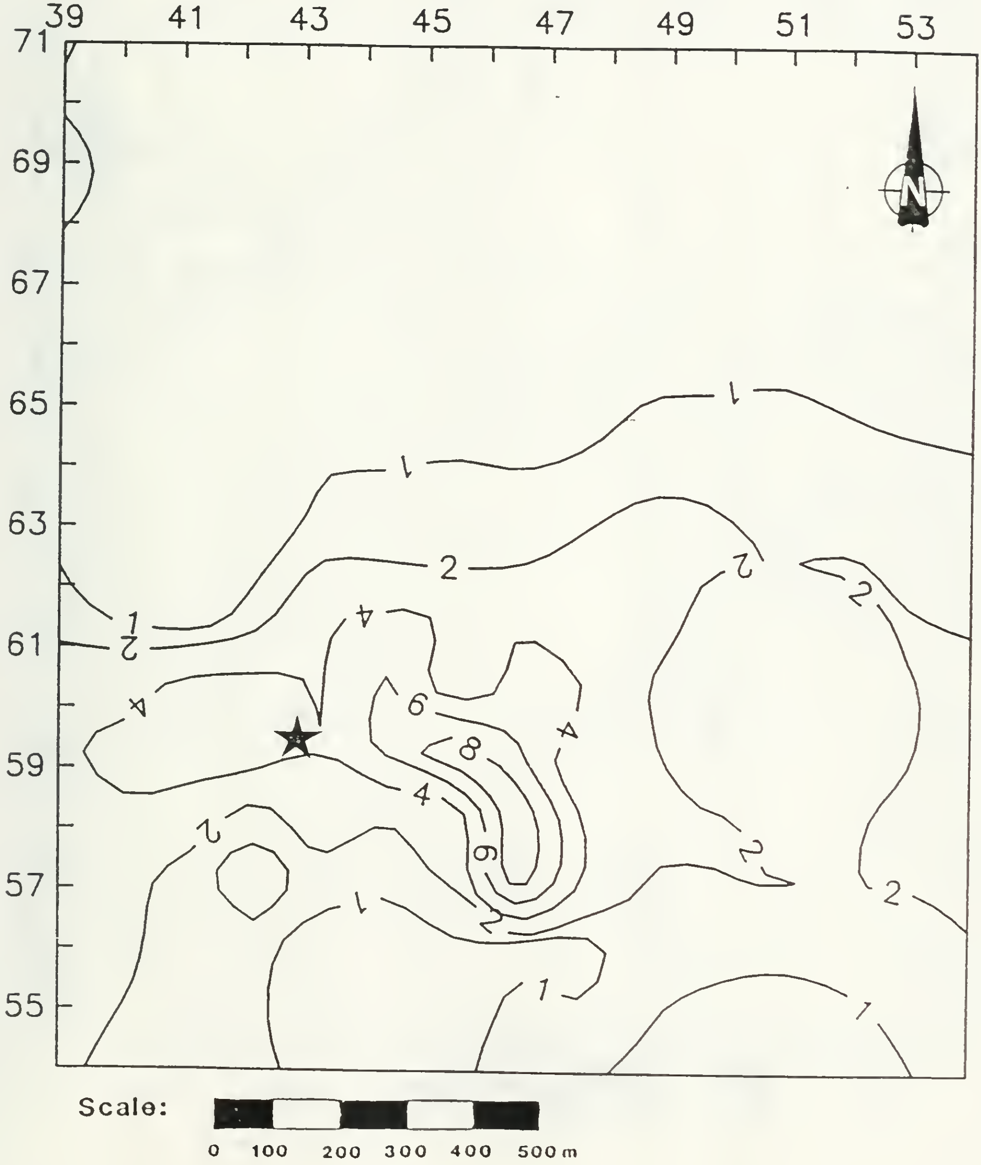


Figure 6

Uranium Concentration (ug/g) in Horizontal Moss Plates Exposed Around Eldorado Nuclear Ltd. (★), 13 July To 04 August

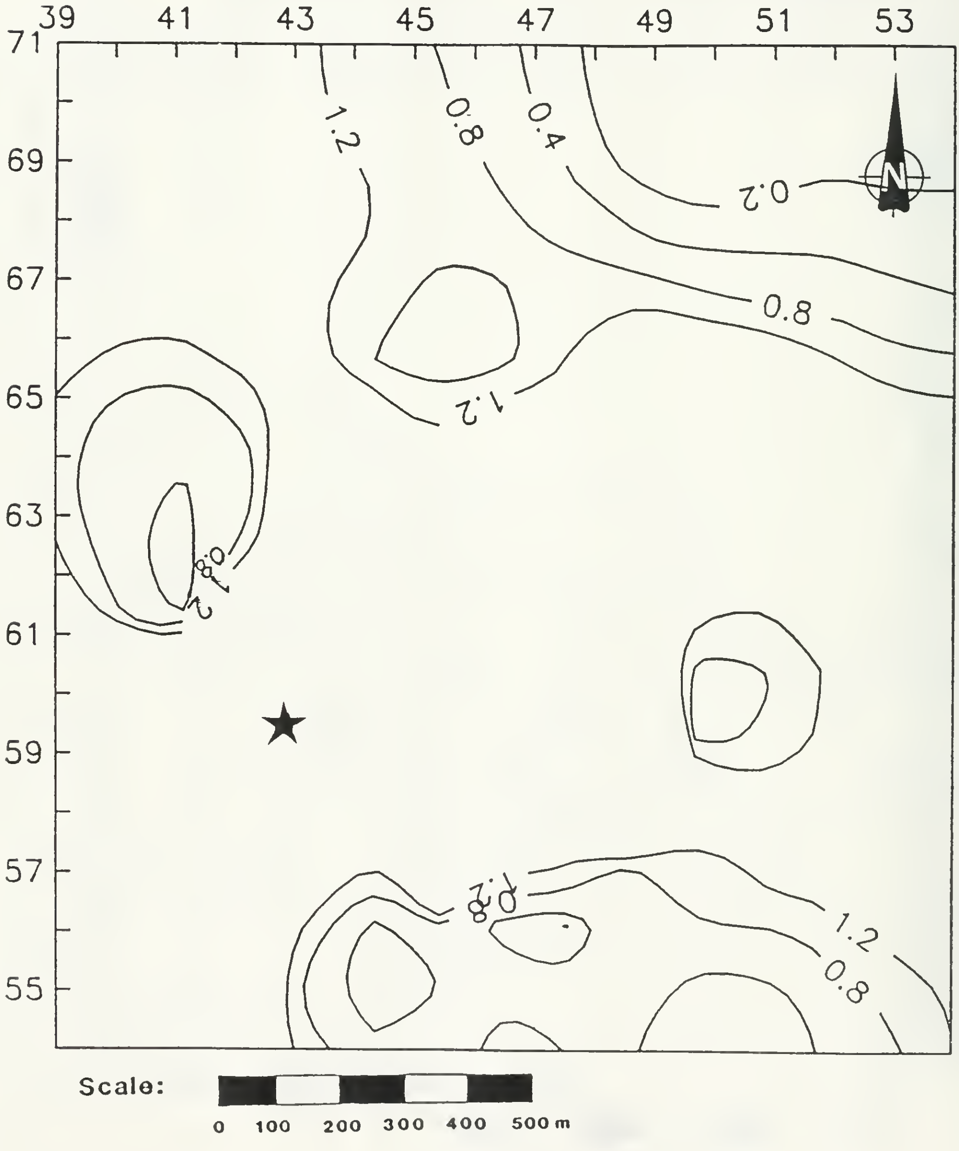


Figure 7

Uranium Concentration (ug/g) in Horizontal Moss Plates Exposed Around Eldorado Nuclear Ltd. (★), 31 August To 03 October

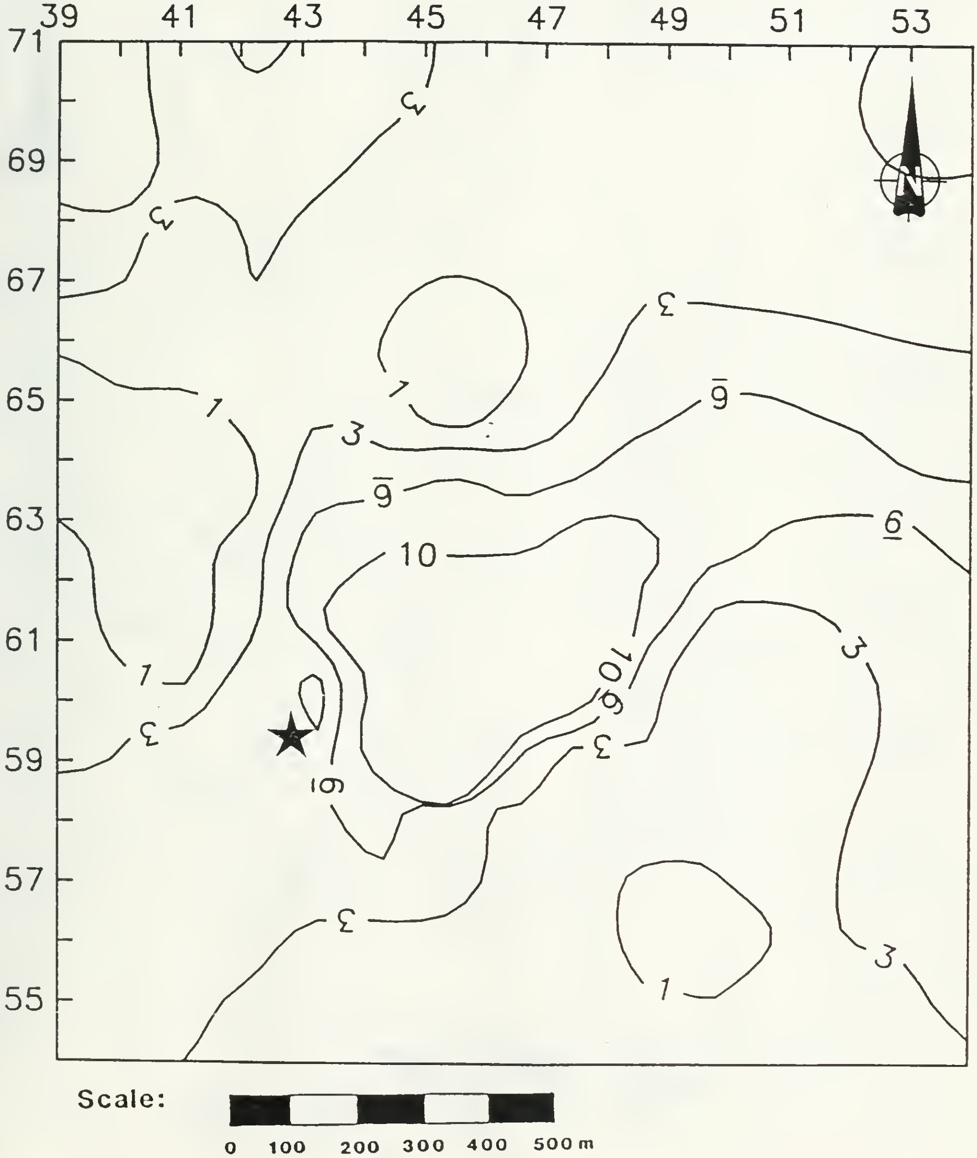


Figure 8

Uranium Concentration (ug/g) in Horizontal Moss Plates Exposed Around Eldorado Nuclear Ltd. (★), 03 October To 02 November

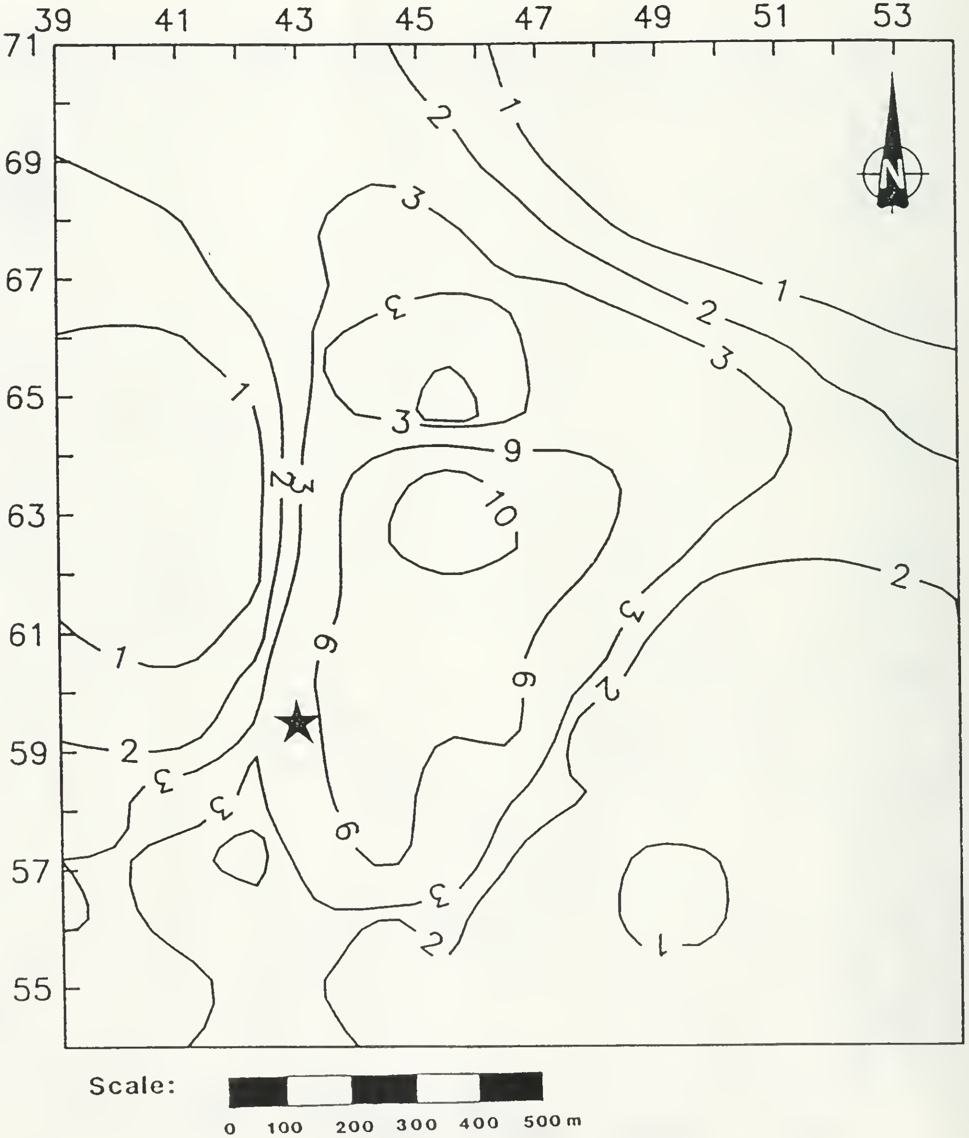


Figure 9

Uranium Concentration (ug/g) In Vertical Moss Bags Exposed Around Eldorado Nuclear Ltd. (★), 22 May To 22 June

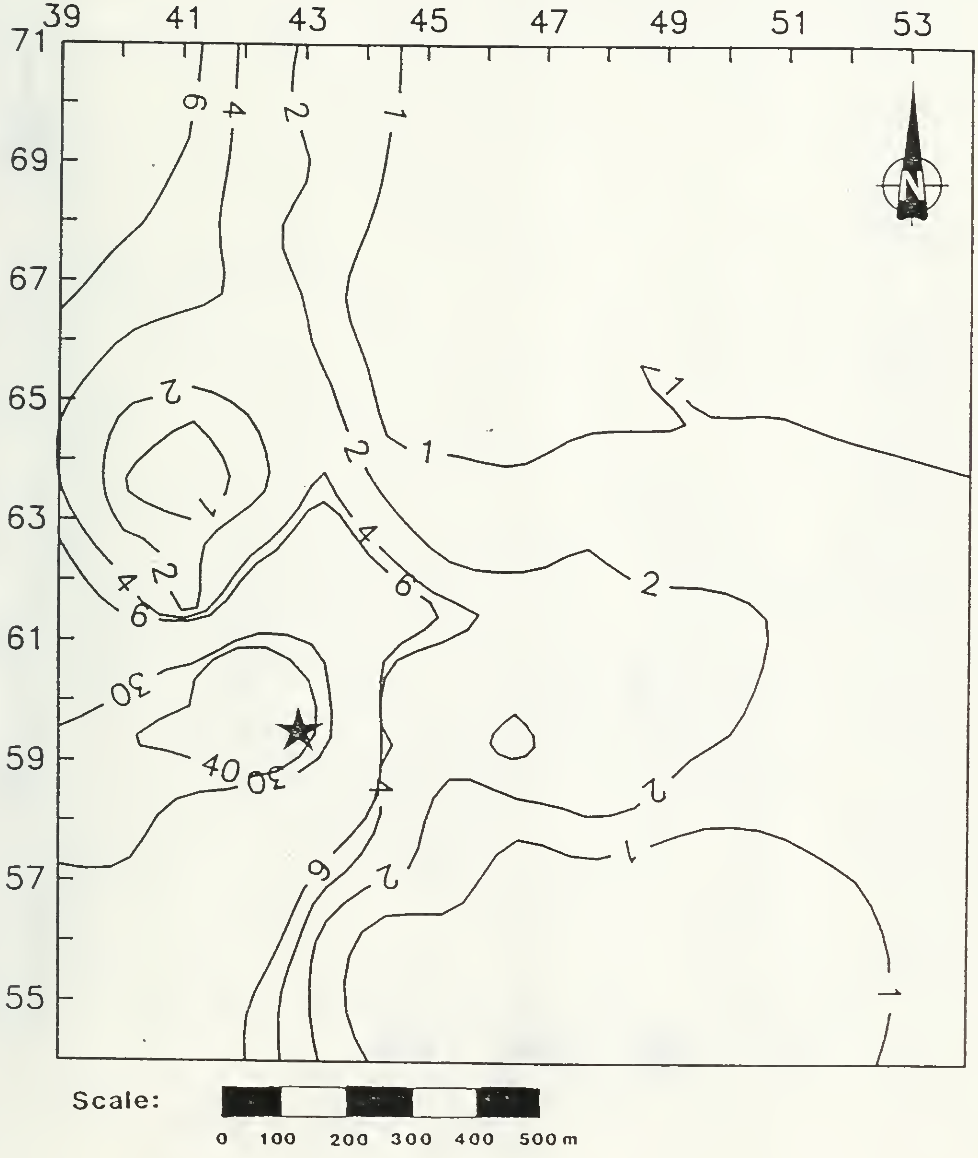


Figure 10
Uranium Concentration (ug/g) in Vertical Moss Bags Exposed Around Eldorado Nuclear Ltd. (★), 22 June To 13 July

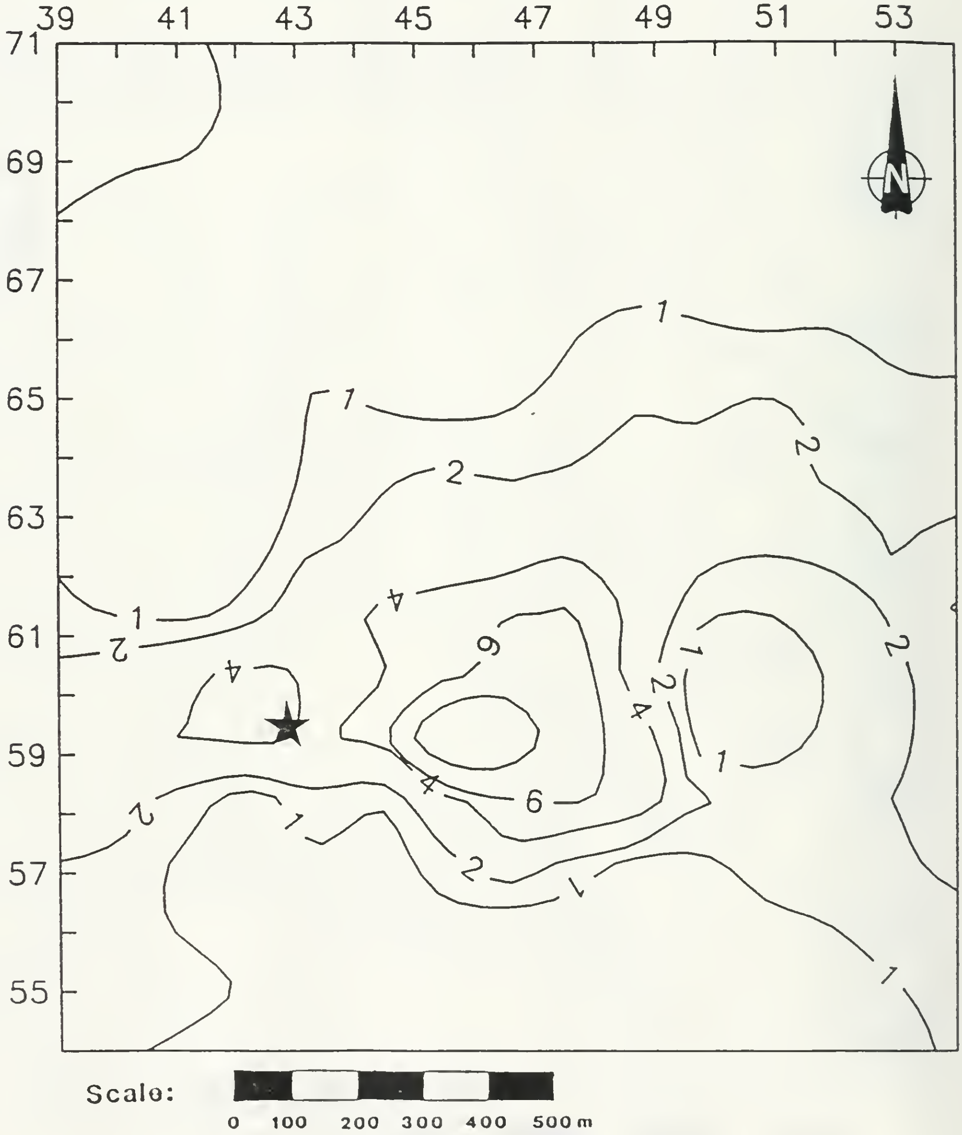


Figure 11

Uranium Concentration (ug/g) in Vertical Moss Bags Exposed Around Eldorado Nuclear Ltd. (★), 13 July To 04 August

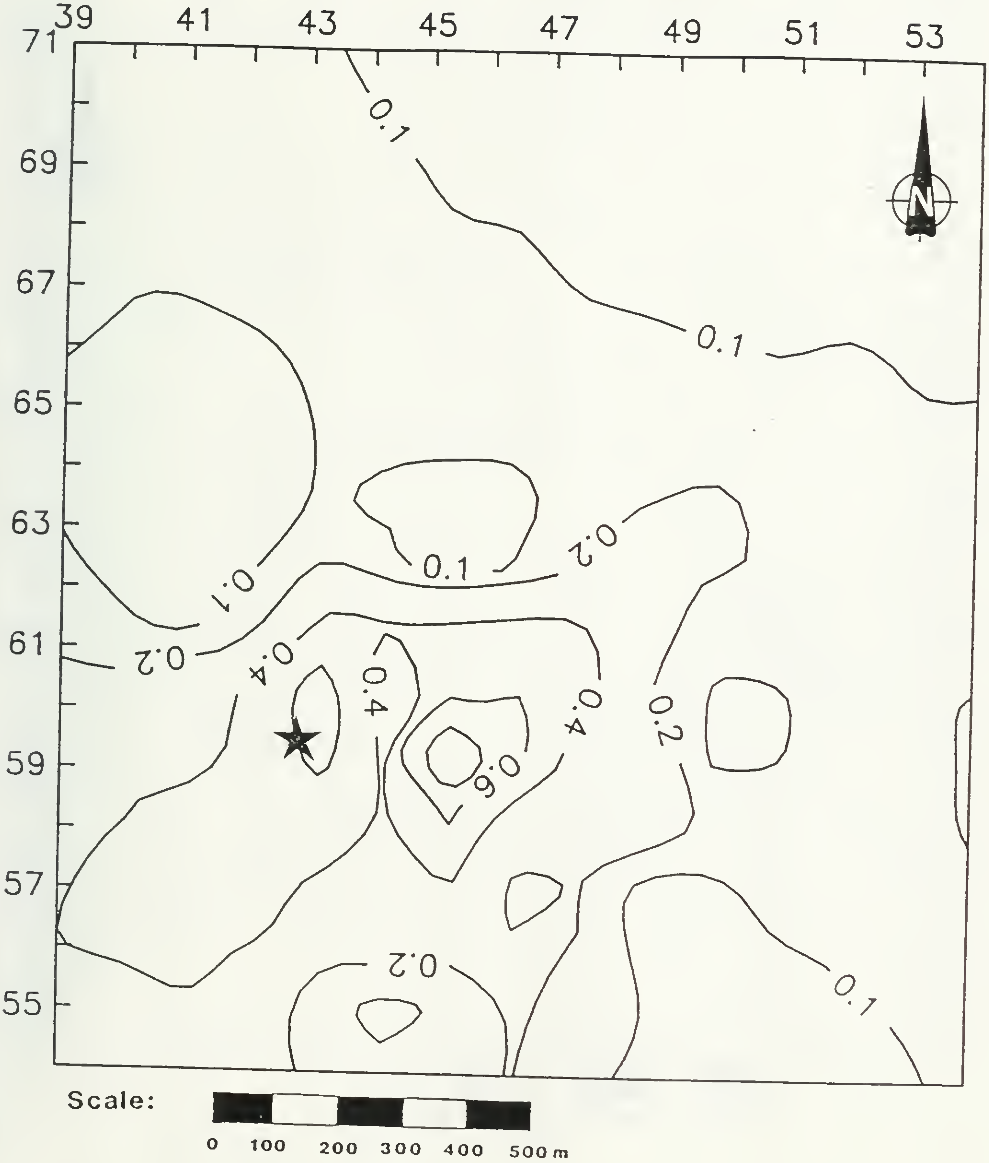


Figure 12

Uranium Concentration (ug/g) In Vertical Moss Bags Exposed Around Eldorado Nuclear Ltd. (★), 04 August To 31 August

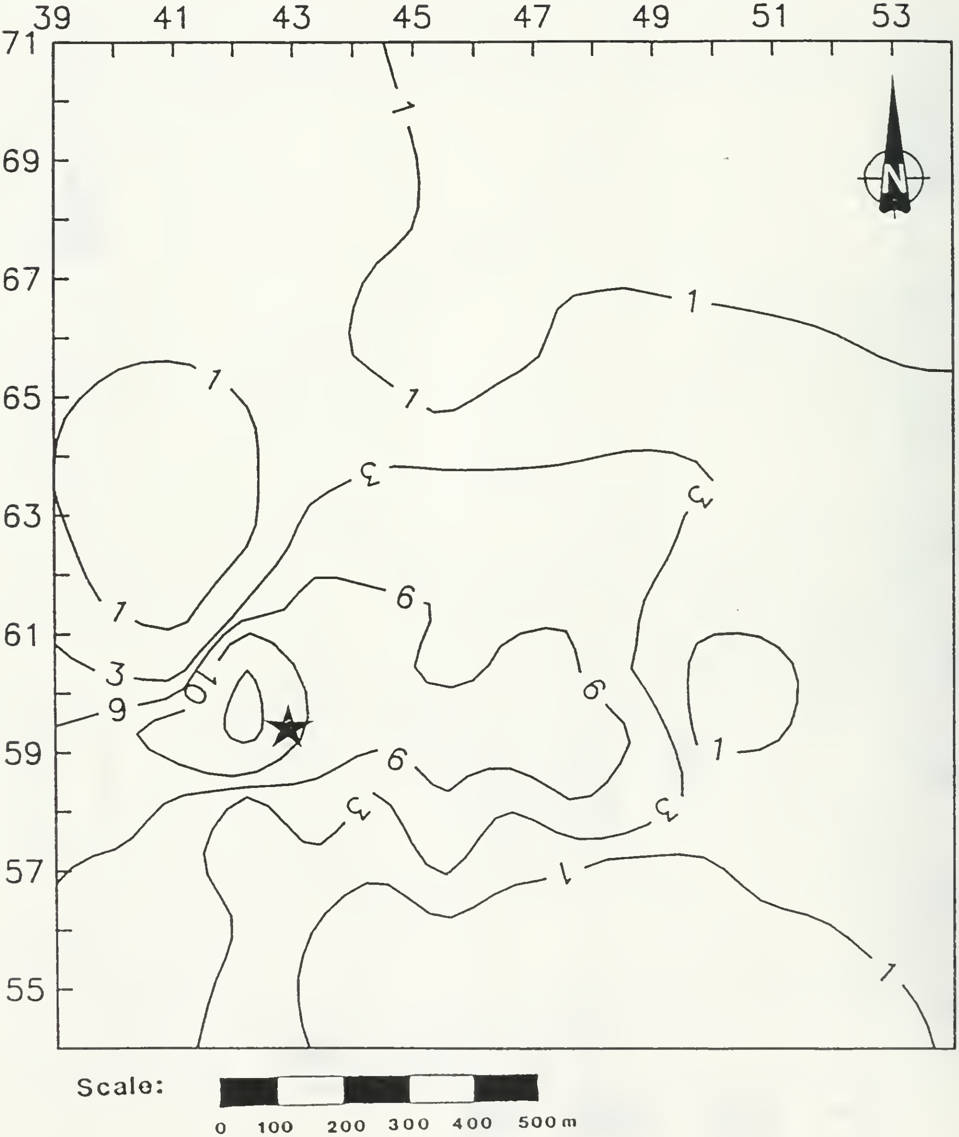


Figure 13

Uranium Concentration (ug/g) in Vertical Moss Bags Exposed Around Eldorado Nuclear Ltd. (★), 31 August To 03 October

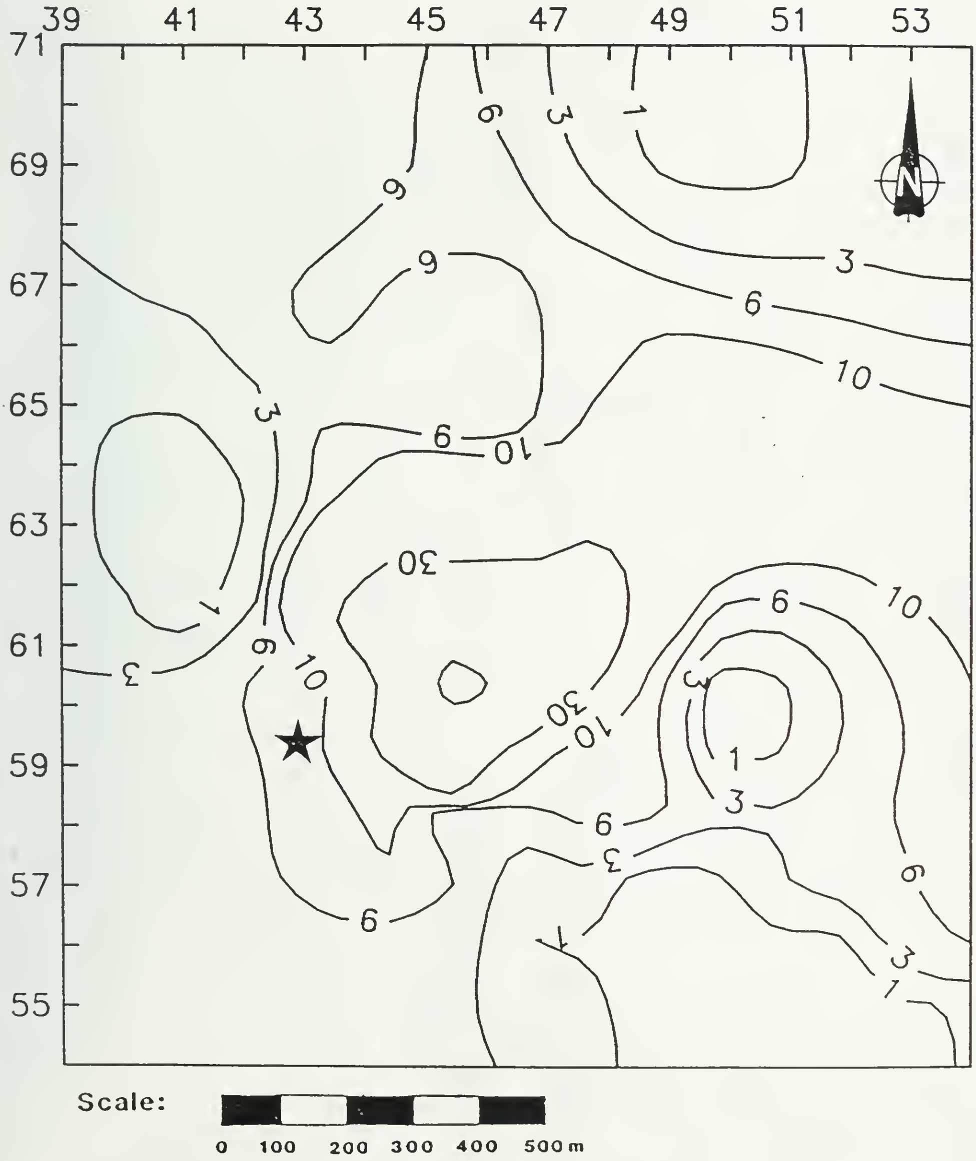


Figure 14

Uranium Concentration (ug/g) in Vertical Moss Bags Exposed Around Eldorado Nuclear Ltd. (★), 03 October To 02 November